Radiometrics theoretical background (R25)

Top

Multi-channel spectra processing performs the following operations on multi-channel airborne radiometric data:

- Spectral noise cleaning
- Live time/Dead time correction
- Energy calibration (correction for photo-peak drift)
- Aircraft, cosmic and radon background correction

Once the spectra have been successfully adjusted, standard potassium, uranium, thorium and total count window data are extracted by integrating each spectrum over the appropriate energy range.

Live/Dead time—introduction

The **dead time** of a gamma ray spectrometer is effectively the time taken by the equipment to analyse a single gamma ray; during this period the equipment is busy and cannot analyse any other gamma rays. You can calculate the true count N from the measured count n if the dead time T is known, using the approximation:

$$N = n/(1–nT)$$

You can measure the dead time for your spectrometer empirically.

The **live time** of a gamma ray spectrometer is the time in a given time interval that the spectrometer is available to accept data. The live time, L will normally be related to the dead time (T) by the formula

$$L = 1 – nT$$

In some systems there may be factors other than the count rate contributing to a reduction in the live time. For example, housekeeping functions such as on-line energy calibration may cause the spectrometer to be unavailable for a short period.

Dead time correction for systems with these features is not accurate enough. Such systems instead measure live time using the spectrometer and record it with the spectral data (See "INTREPID 256 channel spectrum format" in Radiometrics—file formats (R26)).

For systems using live time, the true count is given by

$$N = n/L$$

INTREPID can perform either dead or live time corrections.

Your spectrometer may behave differently for data in the cosmic channel (3–6 MeV), so you may wish to perform dead time correction in the cosmic channel differently, or omit it. INTREPID provides a facility for this. See Cosmic background corrections for details about the cosmic background correction.

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Energy calibration—introduction

INTREPID has a standard set of spectrum data with peaks and troughs typical of the radiometric data you have produced. The standard spectrum depends on the aircraft and the spectrometer. You must determine them empirically for the spectrometer and aircraft that you are using. Count rate peaks and troughs occur at energies that you can use as 'landmarks' for checking the measured energies of your data. It compares your data with this standard to check and adjust the accuracy of the energies reported by your spectrometer. INTREPID 'superimposes' your data on the standard spectrum and looks for the landmark peaks and troughs. If your landmarks occur at a different energy, INTREPID will adjust your reported energy range to conform with the standard spectrum. In this way INTREPID calibrates your spectrometer.

Rather than process the whole spectrum, you can examine a number of energy ranges which contain the best landmarks for the calibration process. These are called **energy windows**.

You can specify the energy windows directly or use the default set provided by INTREPID.

INTREPID performs the calibration process one traverse line at a time. It integrates the spectra for the line and aligns the data in the energy windows with that of the standard spectrum. INTREPID calculates the calibration (the corrected high and low bounds for the whole spectrum) for the whole traverse line and then updates all of the individual spectra in the line using this calibration.

You can find a full description of this energy calibration technique in Minty et al[1]. The technique involves iteratively adjusting the energy bounds of the spectrum using double quadratic minimisation. It does not alter any of the count rates

To ensure that the quadratic minimisation converges, the initial estimation for the energy bounds must be fairly close to the true values. You must specify a nominal spectra energy range for this initial estimation.

1. Minty, B. R. S., Morse, M. P., and Richardson, L.M., 1990, Portable calibration sources for airborne gamma-ray spectrometers: *Expl. Geophys.*, **21**.

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Background corrections—introduction

Radiation not originating from the ground is regarded as background. The background corrections are by far the largest and most difficult correction to make.

There are three main sources of background radiation:

- radioactivity due to the aircraft and its contents
- cosmic radiation
- atmospheric radon (^{222}Rn) and its daughter products.

Radon, cosmic and aircraft background radiation all originate in the atmosphere and in the aircraft and its equipment. The shapes of these spectra are determined from calibration of the airborne acquisition system. Calibration is achieved using a series of test flights. The data from these calibrations is used to compute the various coefficients or spectra which are required to perform the radiometric corrections.

Aircraft background radiation is due to the contamination of the aircraft structure and equipment and the detector itself.

Primary cosmic radiation from outside our solar system and from the sun reacts with atoms and molecules in the upper atmosphere and generates a complex secondary radiation. This radiation reacts with the air, aircraft and detector to produce the cosmic gamma-ray background.

Atmospheric ^{222}Rn and its daughter products—specifically ^{214}Bi and ^{214}Pb, are the major contributors to the background. ^{222}Rn is very mobile and can escape into the atmosphere from soils and rock fissures in response to the 'pumping' action of changing temperatures and pressures. Its daughter products ^{214}Bi and ^{214}Pb attach to airborne aerosols and dust particles and their distribution is thus a function of air movements and wind patterns.

Aircraft background corrections

The aircraft background radiation spectrum is constant. It can be performed either as a full spectrum correction before photo-peak extraction or as a window correction after photo-peak extraction.

Cosmic background corrections

In the lower atmosphere this radiation has a constant energy distribution, but it decreases in amplitude with decreasing altitude. The amplitude of the cosmic spectrum is linearly related to the count rate in the 3–6 MeV range, the so called cosmic channel. If you know the cosmic spectrum corresponding to a cosmic channel base count rate, you can use the cosmic channel count rate for each spectrum to calculate the cosmic background spectrum and subtract it from the spectrum.

Since the cosmic channel has an energy range outside that of the spectral data you wish to use, you may have different arrangements for collecting this data, or your spectrometer may behave differently in the 3–6 MeV range. You may therefore wish to calculate the dead time for the cosmic channel differently. INTREPID has a facility for independent dead time correction in the cosmic channel. See Live/Dead time—introduction for more information about dead time correction.

You can perform cosmic background correction either as a full spectrum correction before photo-peak extraction or as a window correction after photo-peak extraction.

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Radon background estimation

You can estimate the radon background with the full spectrum analysis technique known as the spectral ratio method.

For gamma-ray counts above the Compton continuum, the low energy ^{214}Bi photopeak at 0.609 MeV for atmospheric radiation suffers far less attenuation relative to the ^{214}Bi peak at 1.76 MeV than is the case for radiation from uranium in the ground. Since thorium and potassium sources do not contribute appreciably to these peak count rates, you can use them to estimate the contributions of radon and uranium to the observed spectrum.

Before performing the radon background estimation, you must adjust the spectra for dead time (See Live/Dead time—introduction), energy calibrate them (See Energy calibration—introduction) and remove the cosmic and aircraft background components (See immediately above).

Minty et al[1] used portable calibration sources to measure pure U, Th and K spectra over a range of altitudes, and Minty and Richardson[2] derived aircraft and cosmic spectra for the AGSO system from high-altitude calibration flights. You can derive the radon spectrum from calibration flights at survey altitude over water and in the presence of radon.

The following figure shows the ^{222}Rn spectrum and the U, Th and K spectral components relative to a low energy (0.54–0.68 MeV) window centred on the ^{214}Bi 0.609 MeV photopeak and a high energy (1.65–1.96 MeV) window centred on the ^{214}Bi 1.76 MeV photopeak.

1. ibid

2.Minty, B.R.S., and Richardson, L.M., 1989 - *Calibration of the BMR airborne gamma-ray spectrometers upward-looking detector*, February, 1989. Bureau of Mineral Resources, Australia, Record 1989/8.

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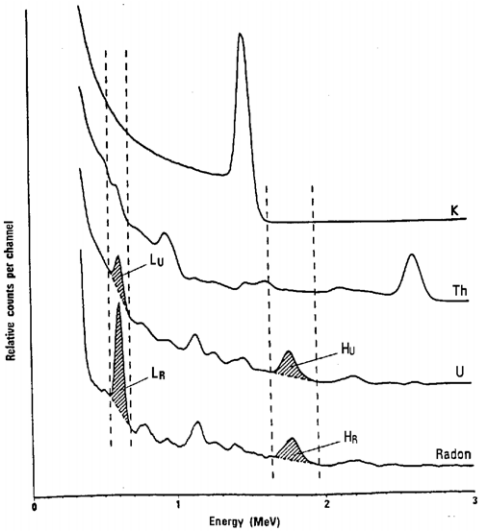
The important feature of these windows is that only the radon and uranium components contribute significantly to gamma-ray counts above the Compton continuum. You can estimate these count rates (the **peak count rates**) by integrating under each peak but above the straight lines used to approximate the Compton continuum.



Let L_{ob} and H_{ob} be the respective observed peak count rates in the low energy and high energy peaks after correcting the spectrum for aircraft and cosmic background. Let L_r and H_r be the radon contribution to the low energy and high energy peak count rates respectively. Similarly, let L_u and H_u be the uranium contribution to the low energy and high energy peak count rates.

Then

$$L_{ob} = L_r + L_u(1)$$

and

$$H_{ob} = H_r + H_u(2)$$

Also, since we can assume that the shape of the uranium and radon components are constant for a particular altitude, we have

$$L_r = c_1 H_r(3)$$

and

$$L_u = c_2 H_u(4)$$

where c_1 and c_2 are constants that can be determined directly from the radon and uranium spectra, respectively.

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Equations 1 to 4 give

$$L_r = (L_{ob} - c_2 H_{ob}) / (1 + c_2/c_1) \quad (5)$$

You can then use the value of L_r with the radon calibration spectrum to calculate the radon background spectrum correction, and subtract it from the observed spectra.

It is most important to correctly perform the energy calibration of the spectra. The Bi^{214} 0.609 MeV photopeak is relatively narrow and you need to energy calibrate the observed spectra to a high degree of precision.

To obtain sufficiently good statistics to calculate the radon background, INTREPID sums the spectra over a defined interval (default 100 readings). It then uses Equation 5 to calculate the amplitude of the radon background spectrum and subtracts it from each individual spectrum over the summed interval. INTREPID repeats the procedure until it reaches the end of the line.

For the purposes of radon background estimation you can specify energy windows surrounding the ^{214}Bi 0.609 MeV and 1.76 MeV photopeaks. INTREPID 's default Radon background calculation intervals are 0.54–0.68 MeV for the 'low' energy ('L') window and 1.65–1.96 MeV for the 'high' energy ('H') window.

INTREPID also supports radon removal using the older upward looking detector method.

Standard 3 (K U Th) channel data generation—introduction

After you have performed the corrections and calibration on the multichannel data, you can extract the potassium, thorium and uranium count rates. The count rate for each element is found by integrating (summing) the counts over a defined energy range, or window. The International Atomic Energy Agency (IAEA) recommends the following energy windows for the three elements:

Potassium	1.370–1.570 MeV
Uranium	1.660–1.860 MeV
Thorium	2.410–2.810 MeV

Using this method for each spectrum (i.e., each integration period / data point) you can produce a complete set of K, Th and U data for your survey.

The calibration spectra

To carry out these adjustments on multi-channel spectra, you need to derive a set of calibration spectra empirically from the aircraft and spectrometer that you are using. The calibration spectra set must consist of five individual spectra, all 256 channel and encompassing the energy bounds of the spectrometer you are using, normally 0.0–3.0 MeV. The five required calibration spectra are as follows:

Aircraft the aircraft background spectrum in counts/100 seconds.

Cosmic the cosmic spectrum corresponding to a count rate of 100 counts/second in the 3–6 MeV cosmic channel.

Standard a typical spectrum at the nominal survey altitude.

Radon a typical spectrum due to Radon at the nominal survey altitude.

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Uranium the spectrum due to uranium from the ground at the nominal survey altitude.

INTREPID only uses the shape of the Standard, Radon and Uranium calibration spectra, so the actual count rates for these spectra in the calibration spectra file are immaterial.

The calibration spectra file must be in ASCII format and have the extension **`.asc`** INTREPID will ignore blank lines and lines starting with #. We have included an abbreviated sample calibration spectra file in this manual (See "Example of calibration spectra file" in Radiometrics—file formats (R26)). You can use this as a model for creating your own file. INTREPID also has a library of example calibration spectra files in the **`config/calibration_spectra`** dir. You can use these pre-existing calibrations files if you cannot derive them for your own data.

Standard 3 corrections theory

The elements Potassium (K), Uranium (U) and Thorium (Th) emit gamma rays. These elements occur in most rocks and soils. The gamma rays are of different energies which you can detect using a differential spectrometer. You can process and analyse this data to provide information about the abundances of the three elements in the rock or soil.

Gamma rays are attenuated by rock and overburden. As a result, approximately 90% of the radiation comes from the top 150 to 200 mm of rock (or 300 to 400 mm of soil cover). Gamma rays are also attenuated by the air between the source and the aircraft. The radiation is reduced by half in passing through each 100 to 130 metres of air.

Compton scattering in the source, air and the detector modifies the energy distribution of the gamma-rays.

The spectrometer in the aircraft also measures a fairly constant background radiation level which is due to sources other than the ground (cosmic, aircraft and atmospheric radon gas). See Multi-channel gamma ray spectrometric processing (C07) for a full discussion of background radiation, dead time and spectrum calibration corrections, as well as calculation of the Potassium, Uranium, Thorium and Total Count data.

We wish to remove the effects of height attenuation and Compton scattering, and end up with count rates in the Potassium, Uranium and Thorium channels which are directly proportional to the abundance of the three elements at the Earth's surface.

The S3GSC process performs the height correction and Compton scattering correction (often called 'stripping' or 'energy stripping') of the Potassium, Uranium, Thorium and Total Count data.

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Compton scattering correction (stripping)—theory

Compton scattering contributes to the uranium and potassium count rates. Scattered thorium radiation contributes counts to the lower energy uranium and potassium channels. Scattered uranium contributes to the potassium channel only. The coefficients for correction depend on altitude, the window widths employed, size, number and spacing of radiation detectors, etc. Our stripping equations are as follows:

$$Nc_{Th} = N_{Th}$$

$$Nc_{U} = N_{U} - \alpha.N_{Th}$$

$$Nc_{K} = N_{K} - \beta.Nc_{Th} - \gamma.Nc_{U} \quad (1)$$

where[1]

N_p is the measured count rate for element p

Nc_p is the corrected count rate for element p

α, β, γ are stripping ratios:

$\alpha = m_\alpha h + c_\alpha$

$\beta = m_\beta h + c_\beta$

$\gamma = m_\gamma h + c_\gamma$

where

m_x = slope (change per metre) of ratio x

c_x = ground level value of ratio x

h = measured clearance (height above ground)

Height correction theory

It is in practice impossible for an aircraft to maintain a constant ground clearance. At different heights radiation from the ground suffers different attenuations due to variations in the mass of air it has to pass through. It is easier to compare data within a survey if you adjust them to a standard distance above ground level. You would typically use the nominal terrain clearance of your aircraft as this standard distance.

In theory you might consider the geometry of the source whilst calculating this height correction, in order to use a more complex attenuation formula. In practice, the simpler process of applying a uniform exponential correction provides a satisfactory height correction, as long as the ground clearance varies within reasonable limits.

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1. For the AGSO system

α = .000518 h + 0.45500

β = .000804 h + 0.44100

γ = .000976 h + 0.80500

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Our correction is based on the formula:

$N_0 = Ne^{-u(H-h)}(2)$

where[1]

N_0 = height-corrected count

N = height-uncorrected count (Nc from the stripping correction (See Compton scattering correction (stripping)—theory)

h = height above ground (measured and corrected for temperature and pressure if possible (see below))

H = nominal flying height

u = attenuation coefficient (different for each energy of the gamma-rays—u_K, u_U, u_{Th})

The attenuation of the gamma rays with height in reality relates to the mass of the column of air below the aircraft. This depends on the air pressure and temperature. If air temperature and pressure data are available then you can adjust the measured height of the aircraft above ground level for fluctuations in temperature and pressure.

We use the formula

$$h = \frac{(t_0\ p_1\ h_m)}{(t_1 + t_0)\ p_0}$$

where

h = effective height

h_m = measured height

t_0 = 273.15

p_0 = 1013.25

t_1 = measured temperature (degrees C)

p_1 = measured air pressure (millibars)

In practice the exponential attenuation correction for height does not yield meaningful results for data which is collected above about 250 metres. It is common practise to ignore data obtained from heights above this level.

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1. For AGSO's system, current values of u are:

for total count (integral) u = 0.006560

for potassium u = 0.007550

for uranium u = 0.005570

for thorium u = 0.005570

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Sensitivity conversions—theory

If you make traverses over a test strip of known ground concentrations in potassium, uranium and thorium, and compare your spectrometer data with the known concentrations, you can establish a relationship between the count rates recorded by your spectrometer and the actual ground concentrations. You can thus establish the sensitivity of the gamma ray spectrometer in terms of counts per unit concentration per unit time. You can use this sensitivity to scale the corrected radiometric count rate data to give ground concentrations. This provides a degree of data independence from survey parameters such as crystal volume and survey flying height.

The best estimates for K, U, and Th are obtained using spectral smoothing (NASVD/MNF) followed by conventional 3-channel processing.

It is standard practice to report total count in units of nGy/h (the equivalent air-absorbed dose rate at 1m above the ground).

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